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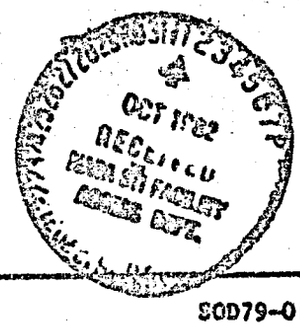
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DEVELOPMENT AND DEMONSTRATION OF MANUFACTURING PROCESSES FOR FABRICATING GRAPHITE/LARC-160 POLYIMIDE STRUCTURAL ELEMENTS

9TH QUARTERLY PROGRESS REPORT

JUNE 16, 1980 THROUGH SEPTEMBER 15, 1980

CONTRACT NAS1-15371

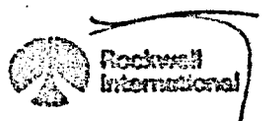
PART IV, PARAGRAPH B

(NASA-CR-159303-Pt-4B) DEVELOPMENT AND DEMONSTRATION OF MANUFACTURING PROCESSES FOR FABRICATING GRAPHITE/LARC-160 POLYIMIDE STRUCTURAL ELEMENTS, PART 4, PARAGRAPH B Quarterly (Rockwell International Corp., G3/24

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PREPARED FOR
MATERIALS DIVISION
NASA LANGLEY RESEARCH CENTER
HAMPTON, VA.



Space Transportation Systems
Development & Production Division
Space Systems Group

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Rockwell International

Space Transportation System
Development & Production Division
Space Systems Group

FOREWARD

This quarterly technical report was prepared by the Space Systems Group of Rockwell International, under contract NAS1-15371 for the Materials Application Branch, Materials Division, NASA Langley Research Center, Hampton, Virginia. Mr. Robert M. Baucom is the NASA Program Manager.

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1.0 INTRODUCTION

Contract NAS1-15371 is the third NASA/LaRC program of Project CASTS, Composites for Advanced Space Transportation Systems. The first program utilized NR150-B2 polyimide resin and was conducted by General Dynamics, San Diego. PMR-15 polyimide resin was the subject of the second program conducted by Boeing Aerospace Company. The third program, NAS1-15371, utilizing LARC-160 polyimide resin, was awarded to the Space Systems Group of Rockwell International.

The three programs have as a common objective, the development and demonstration of technologies to implement structural application of graphite polyimide for 316C (600F) service environment. Technologies evolved from these programs will be transferred to Space Shuttle structural flight hardware according weight savings not attainable with conventional composite materials.

2.0 PROGRAM PLAN

The program is divided into two parts: process development and demonstration components. Each consists of several tasks. The program schedule is presented in Figure 1. The following briefly describes the objective of each task:

Part 1. Process Development

Task (a) - Develop a quality assurance program including specification for Celion/LARC-160 polyimide materials, quality control of materials and processes, including studies of the effects of monomer and/or polymer variables and prepreg variables on the processibility of Celion/LARC-160 prepreg and on the mechanical properties of test specimens fabricated from the prepreg, and NDI of fabricated components.

Task (b) - Develop processes for fabricating laminates, hat and "I" stiffeners, honeycomb core panels, and chopped fiber moldings.

Task (c) - Fabricate specimens and conduct tests to qualify the processes for fabrication of demonstration components.

Part 2. Demonstration Components

Task (d) - Fabricate and NDI three (3) laminates 61x22-cm (24x48-in.) with 0, $\pm$ 45° lay up symmetrical about the neutral axis. Laminate thickness will be 0.08-cm, 0.15-cm, and 0.32-cm (0.030 in., 0.060 in., and 0.125 in.).

Task (e) - Fabricate and NDI three (3) secondarily bonded hat-stiffened skin-stringer panels 23-cm (9 in.) wide x 122-cm (48 in.) long with 3 lengthwise stiffeners.

Task (f) - Fabricate six (6) honeycomb core panels 25.4x25.4-cm (10x10-in.) with 0.15-cm (0.060 in.) thick face sheets with 0°, 90°, layup symmetrical about the neutral axis of the panel. The honeycomb core will be 2.54-cm (1 in.) thick.

Task (g) - Fabricate six (6) chopped fiber moldings according to a specimen design mutually agreeable to Contractor and Contracting Officer's technical representative.

Task (h) - Fabricate a representative component of a Space Shuttle aft body flap that is mutually agreeable to the Contractor and Contracting Officer's technical representative.

3.0 PROGRAM PROGRESS

3.1 TASK (a) - QUALITY ASSURANCE PROGRAM

3.1.1 Chemical Characterization of LARC-160 Polyimide Resin

Liquid chromatographic analysis of three repeatability batches has been made and compared to previous Hexcel standard production and Variables Study LARC-160 resins. Identification of all the Hexcel materials studied in the program is given in Tables 1 and 2.

The liquid chromatographic (HPLC) procedure used to analyze the BTDE and NE ester components in the LARC-160 materials is the same as that described in previous reports. The relative amount of BTDA tetraacid (BTA) in the Hexcel LARC-160 intermediate ester mixtures is shown in Figure 2. The three repeatability batches are found to be low in BTA as well as quite consistent. A similar conclusion is evident for BTA levels in the neat resin and prepreg batches from the data in Figure 3. The variation in BTDE monoethyl ester is shown in Figure 4 for Hexcel intermediate ester batches and Figure 5 for neat resins and prepregs. The repeatability batches show a level of monoester comparable to the Vairable Study materials.

The cause for the variability of BTA and BTDE monoethyl ester noted previously in Hexcel LARC-160 resin materials is becoming clearer. Early in the program it was observed that both BTA and particularly BTDE monoester levels were much higher in Hexcel standard production runs of LARC-160 than in the Variables Study batches. The reason for this difference was believed due to the better mixing in the smaller Variables Study resin kettles compared to the larger production reactors. Recent IR&D experiments have indicated that a high viscosity during the co-esterification of NA and BTDA does result in incompete conversion of BTDA to the desired BTDE diester. LARC-160 intermediate esters prepared under dilute solvent conditions show only a trace of BTA and BTDE monoester.

A recent problem which occurred was the very poor physical properties of laminates produced from resin Runs 15 and 16 of the Variables Study. Liquid chromatographic analysis of these batches showed one unusual feature, that of a high concentration of BTA (see Figures 2 and 3). It is not, however, believed to

be caused by the same processing factors as described above. One reason is that the BTDE monoethyl ester content is not nearly as high in Runs 15 and 16 as would be expected if the above mechanisms were responsible. The most likely source of residual BTA appears to be hydrolysis of BTDA due to moisture contamination of the raw materials supply for the Variables Study. It is not certain that excessive BTA is responsible for the high porosity of laminates from Runs 15 and 16, however, BTA is known to be more sluggish than BTDE esters in reacting with amines to form polyamide acids. Hexcel is currently preparing replacement resins for Runs 15 and 16 using fresh BTDA.

The relative nadic ester endcap concentration in LARC-160 resin materials is shown in Figures 6 and 7. Both the reproducibility and relative level of end-capper in the repeatability batches are satisfactory. A similar result is shown for the BTDE diethyl ester in Figures 8 and 9. The range of BTDE triethyl ester in the LARC-160 intermediate ester batches is shown in Figure 10. Only a small amount of this component is present in the recently tested repeatability batches.

3.1.2 Resin Variables Study Program

Unidirectional laminates, 15.2x15.2-cm (6x6-inches) and 14-plies thick, were laid up from each 4.5Kg (10 lb.) batch of prepreg tape received from Hexcel for the repeatability and storage/out time phase of this program. Because of priorities, laminates could not be processed at the end of one month storage as proposed by the test program schedule as presented in the 7th Quarterly report. Therefore, it was decided that the time of processing would be changed to two, four, and six months.

Laminates, representative of each of the three repeatability batches, were removed from storage at the end of the second month (July) and processed. However, during autoclave cure an electrical malfunction caused a delay in pressure application with the result that the laminates were unusable. A second set of laminates were removed and processed. Again an autoclave malfunction, which in effect simulated a bag rupture, rendered the laminates unusable for this evaluation.

The autoclave has since been repaired and laminates, four months storage, have been submitted for processing.

3.2 TASK (b) - PROCESS DEVELOPMENT

3.2.1 Chopped Fiber Molding Process Development

Development of processes for chopped fiber molding was initiated during this report period. Material for this phase was obtained from U. S. Polymeric in the form of 15.2-cm (6 inch) wide unidirectional tape. Physical properties of the prepreg are as follows:

- Resin Solids: 40%
- Volatiles: 11.8%

- Fiber areal weight: 67 grams/m^2
- Calculated thickness, 60% fiber volume: 0.0064-cm (2.5 mils)/ply

The tape material was chopped transverse to the filament direction into random width strips of 1.25 to 2.54-cm (0.5 to 1.0 inch). These strips separated into pieces 0.25 to 3.0-cm (0.1 to 1.2 inch).

Development of chopped fiber molding processing was accomplished using an ASTM D790 flexure specimen molded in an ASTM D647 compression mold. The flexure mold and typical molded coupons are shown in Figure 11.

A single stage insitu imidizing/molding cycle was used in the first process evaluation. The procedure was as follows:

- Load mold with as chopped material: 7.11 grams calculated to yield a coupon 0.254x1.27x12.7-cm (0.1x.5x5.0-inch). Calculated loss from volatiles and resin flash was 0.5 grams. Net material weight requirement for a 60% fiber volume is 6.41 grams.
- Place mold in 190C (375F) preheated press
- When material reached 190C (375F), stage one hour.
- Raise temperature to 316C (600F) and close mold, pressure 689.5KN/m^2 (100 psi).
- When part reached 204C (400F) apply 13790 KN/m^2 (2000 psi) pressure.
- Cure part at 316C (600F) for one hour.
- Remove part from press hot and clean up.
- Postcure freestanding in air circulating oven. Raise oven temperature from room temperature to 316C (600F) for 4 hours. Force cool to room temperature.

In analyzing the insitu imidizing/cure molding process from the standpoint of mold time utilization, it was more practical to imidize the molding compound before changing the mold. This eliminated one hour in the mold required for imidizing. Additionally, insitu imidization may not allow efficient removal of volatiles from parts having a large mass resulting in voids or blisters. Therefore a two stage process, chopped prepreg imidizing and separate cure cycle, was evaluated. The cycle follows the recently developed Celion/LARC-160 tape prepreg imidizing and cure cycle described in the 8th Quarterly Report under Task (b).

The process is described as follows:

- Chopped unidirectional prepreg was spread uniformly over a teflon sheet positioned in a shallow pan.
- Material was imidized in an air circulating oven by raising the temperature from room temperature to 190C (375F) and staging at temperature for one hour.

- Total prepreg volatiles remaining after imidizing ranged between 1.5 to 2.7% in individual batches tested. Physical properties are presented in Table 3.
- The flexure specimen mold was loaded with the net imidized material required, 6.41 grams for a target fiber volume of 60%, to form a 0.25-cm (0.10 inch) thick coupon.
- The mold was placed in a pre-heated, 316C (600) press and closed to contact position.
- When the part temperature reached 204C (400F), 13790 KN/m^2 (2000 psi) pressure was applied.
- The part was cured at 316C (600F) for one hour.
- The mold was removed hot from the press and disassembled.
- The flexural coupon was easily pressed from the mold using an arbor press.
- The coupons were postcured for 4 hours at 316C (600F) in a free-standing position as previously described.

3.2.2 Chopped Fiber Molding Process Development Results

The CF1-1 coupon molded using the simple stage cycle had minimal resin/fiber flashing, indicating resin was staged correctly. The coupon was uniform in thickness, 0.200 to 0.206-cm (0.079 to 0.081 inch), with smooth molded surfaces. However, the specimen target thickness, 0.254-cm (0.10 inch), was not achieved due to the resin/fiber flashing.

Flexural strength and elastic modulus properties were exceptionally high for a molding compound, 565 of KN/m^2 (81.9 ksi) and 78 MN/m^2 (11.4 msi) respectively. Partial cause of high mechanical properties can be attributed to fibers being aligned predominately in the zero degree direction due to mold geometry. Detailed prepreg and composite physical and flexural properties are presented in Table 3.

The two stage cycle, separate imidizing and cure produced specimens with equivalent quality to the one specimen molded using the single stage cycle. Three flexure coupons (CF1-1, CF1-3, and CF1-4) were molded and tested, two at room temperature and one at 316C(600F). This process produced specimens very close to calculated thickness, 0.248 to 0.251-cm (0.098 to 0.099 inch). Flexural strength and elastic modulus properties at room temperature were similar to those achieved using the single stage cycle. Significantly, the 316C (600F) properties remained high, 498M KN/m^2 (72.2 ksi) ultimate strength and 7240 MN/m^2 (10.5 msi) elastic modulus. Detailed physical and mechanical properties are presented in Table 3.

3.3 TASK (c) - FABRICATION AND TEST

3.3.1 Process Verification - Chopped Fiber Molding

Five tensile coupons (CT1-1, CT1-2, CT1-3, CT1-4, and CT1-5) ASTM D651 standard configuration, were molded in an ASTM D647 steel compression mold using the two stage cycle described in 3.2.1. Figure 12 shows the tensile coupon compression mold and a molded coupon.

Random chopped unidirectional prepreg tape described in 3.2.1 was used in molding coupon specimens. Molding compound weight requirements were determined using water volume displacement. Net material requirement was determined to be 32.6 grams to yield a coupon with a test section 0.318-cm (0.125 inch) and 60% fiber volume.

Cosmetic quality of the tensile coupons was excellent: resin/fiber flashing was minimal and good conformance to the sharp mold corners. Tensile strength was exceptionally high for a molding compound, averaging 194 MN/m^2 (28.1 ksi) at room temperature. Average strength at 316C (600F) was 184 MN/m^2 (26.7 ksi); a loss of 9.6 MN/m^2 (1.4 ksi) compared to room temperature values. Elastic modulus properties were not determined due to the configuration of the specimens. Detailed tensile coupon prepreg and composite physical and mechanical properties are presented in Table 4.

Prototype parts of the demonstration component, design shown in Figure 13, were made using the molding compound and two stage cycle described in 3.2.1. The compression mold loaded with compound is shown in Figure 14. Mold volume was determined by water displacement. Imidized material required to produce a net part, with 60% fiber volume, was calculated to be 227.7 grams. An additional five grams was added to allow for resin fiber flashing.

Compression Molding Demonstration Part No. 1

The compression molding two stage cycle described in 3.2.1 was employed in fabricating the first part. The part was easily removed hot from the mold using an arbor press. The web of the part blistered severly as shown in Figure 15. Blistering was probably caused by (1) expansion of a minor volatile entrapment on removal of the hot molding or (2) insufficient staging of the material mass (232.7 grams). Molded part definition was excellent, with sharp corners well defined and smooth surfaces. Both long and short fibers were well blended with the resin matrix, with no signs of brittleness.

Compression Molding Demonstration Part No. 2

The same processing was employed as for the first part except that the prepreg molding compound was imidized at 199 to 204C (390 to 400F) for one hour with no significant change in volatile loss and the part was force cooled to less than 93C (200F) before removing pressure.

This part showed no signs of blistering. However, conformance of the part to sharp radii and corners of the mold and interlaminar bond was poor indicating a lack of flow due to over imidizing of the prepreg. Figure 16 shows a discrepant area in this prototype part.

Compression Molding of Demonstration Part No. 3

The same processing was used as for molding the first part except that the part was removed after force cooling to less than 93c (200F) under 13790 KN/m^2 (2000 psi) pressure. There was no sign of blistering in any area of the part and excellent mold conformance was attained. The molding is shown in Figure 17.

The posteure for the tensile coupons and three demonstration parts for process verification followed the 4 hour, 316C (600F) free standing cycle described in 3.2.1. No blistering occurred during the posteure process.

3.3.2 Commercial Chopped Fiber Evaluation

Celion/LARC-160 chopped fiber molding compound was obtained from U. S. Polymeric. The fiber length was uniform, 1.27-cm (0.5 inch) rather than random as produced in the laboratory as described in 3.2.1. Physical properties of the commercially prepared molding compound are as follows:

Resin Content (%): 36.8 (Target: 38 $\pm$ 3%)

Volatiles (%): 11.6 (Target: 12 $\pm$ 3%)

Fiber areal weight (gm/m^2): 153.7 (Target: 150 $\pm$ 3)

As with the laboratory prepared chopped fiber, the 1.27-cm (0.5 inch) strips, cut transverse to the tape width, broke into random widths of 0.25 to 2.5-cm (0.1 to 1.0 inch). The material was packaged in a polyethylene bag. The as received material was fairly tacky.

The material was used for molding six flexure (GE1 through GE6) and seven tensile (GE13 through GE19) coupons by the two stage cycle, separate immidization and cure, described in 3.2.1 except that the molded parts were cooled to less than 93C (200F) under 13790 KN/m^2 (2000 psi) pressure. Cosmetic appearance of the molded coupons before and after free standing posteure, 4 hours at 316C (600F), was excellent.

The tensile and flexure coupons were tested at room temperature and 316C (600F). For the 316C testing, the coupons were stabilized at temperatures for 10^{+5}_{-0} minutes.

Flexure and tension properties were significantly lower than obtained in the first series of tests. For example, room temperature and 316C (600F) flexural strength and elastic modulus properties were less than one half of the original tests. Ultimate tensile strengths were similar. Detailed flexure and tensile properties are described in Tables 3 and 4. The cause of lower mechanical properties is attributed to the short fiber length, 1.27-cm (0.5

inch), of the molding compound, resulting in resin matrix to fiber shear failure modes. Initial specimen failure modes were by combined fiber tension and minor shear resulting in higher mechanical properties. Failed specimens are shown in Figure 8.

An additional possible contributor to the mechanical properties was the fiber areal weight of the tape used to produce the molding compound. The relatively low fiber areal weight (66 grams/m^2), used in the laboratory produced compound, provides a more homogeneous distribution of fiber to resin in the molded composite. This in turn gives a high ratio of fiber surface area to resin matrix, which yielded major tensile and minor shear failure modes with corresponding high mechanical properties.

To obtain mechanical properties more in line with those realized in the initial tests, 1.8 Kg (4 lbs.) of Celion/LARC-160 molding compound has been purchased from U. S. Polymeric to the following requirements:

Resin solids (%): 38 $\pm$ 3

Volatiles (%)L 12 $\pm$ 3

Fiber Areal Wt. (grams/m^2): 67 $\pm$ 3

Chopped Fiber Length: 2.54-cm (1.0 in.)

Flexure tensile coupons will be molded from this material and tested.

DEVELOPMENT OF CELION/LARC-160 STRUCTURAL ELEMENTS - NAS1-15371
PROGRAM SCHEDULE

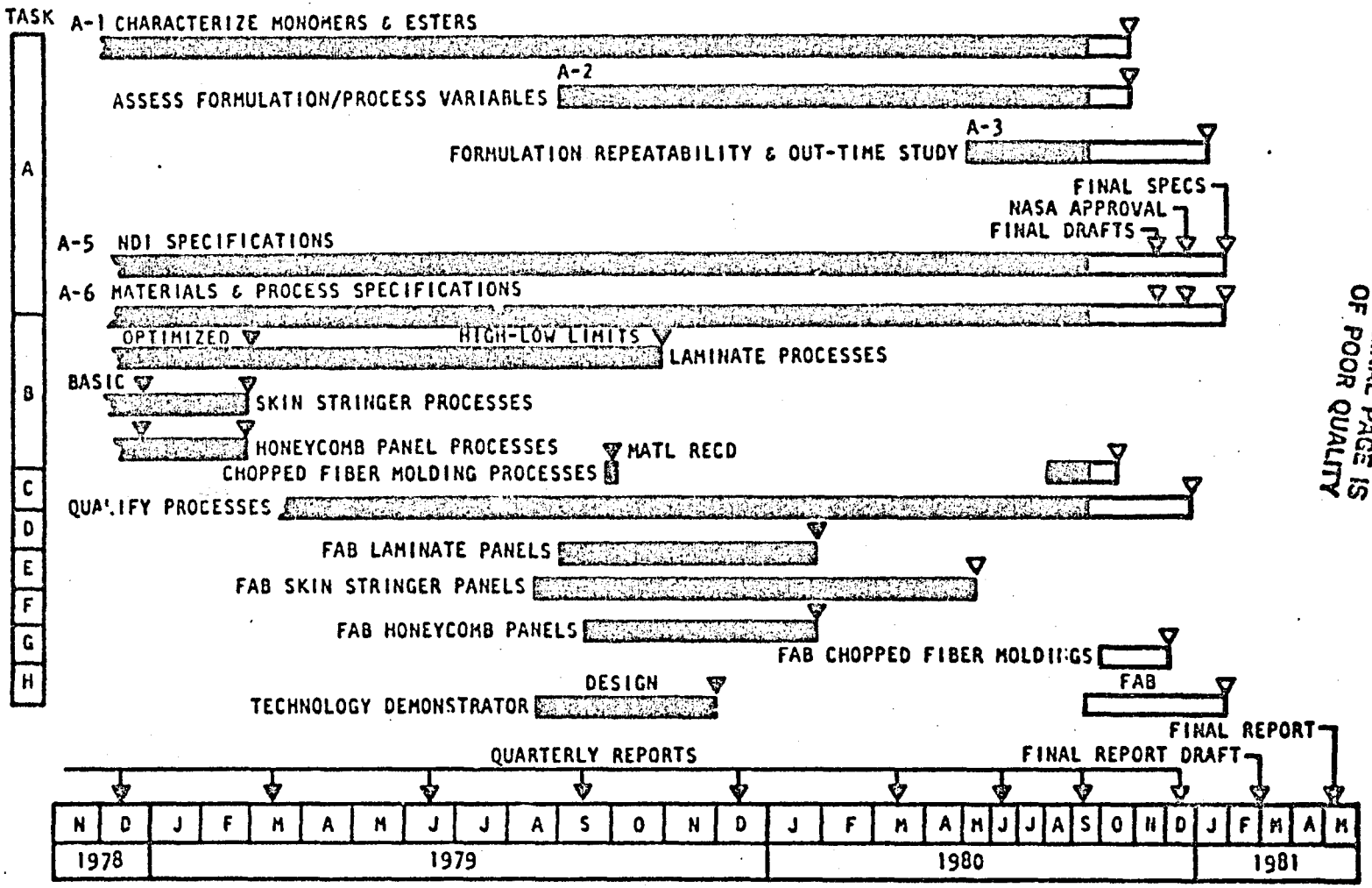
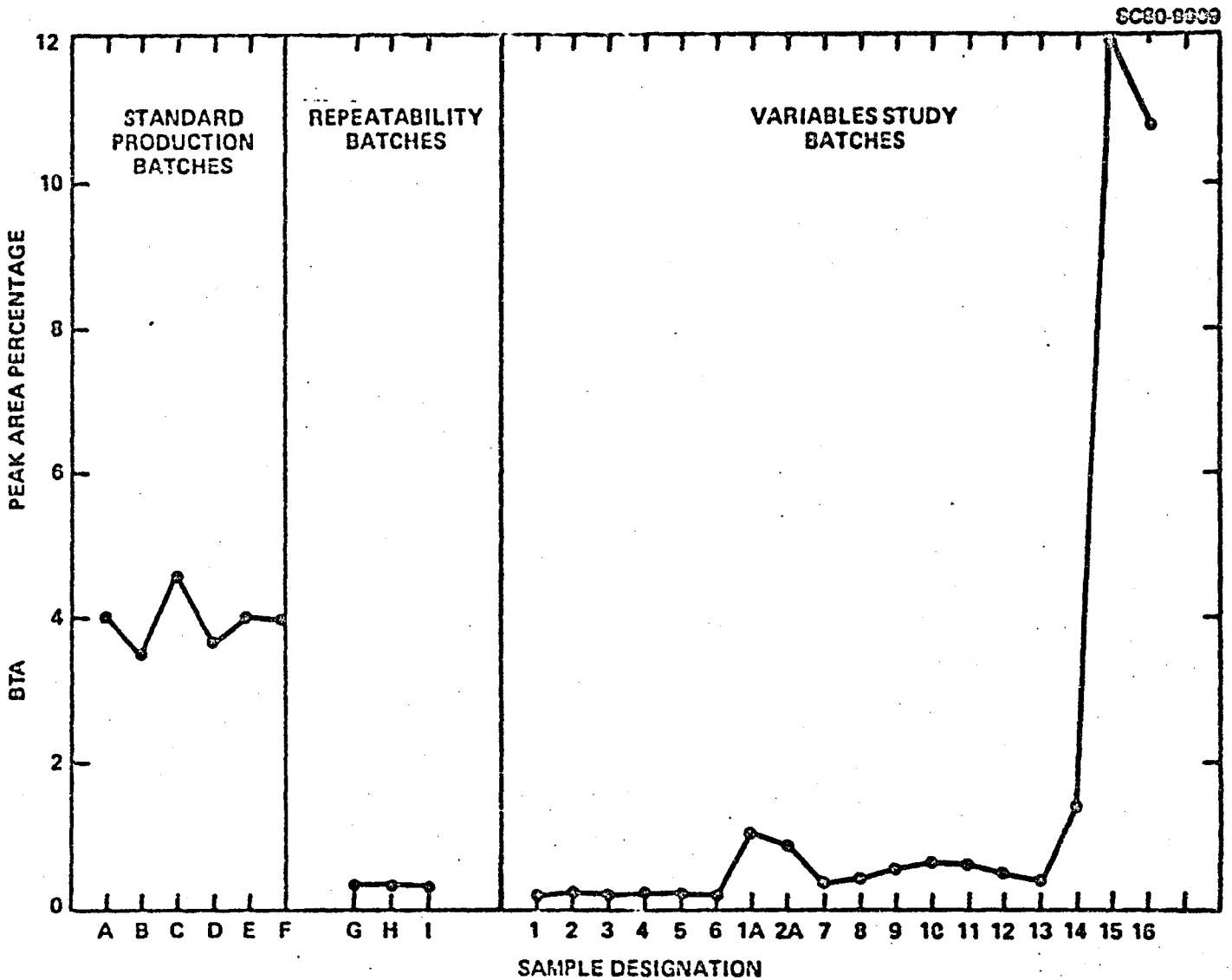


Figure 1.

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Figure 2. Liquid Chromatographic Analysis of BTDA Tetraacid in Hexcel LARC-160 Intermediate Ester Mixtures.

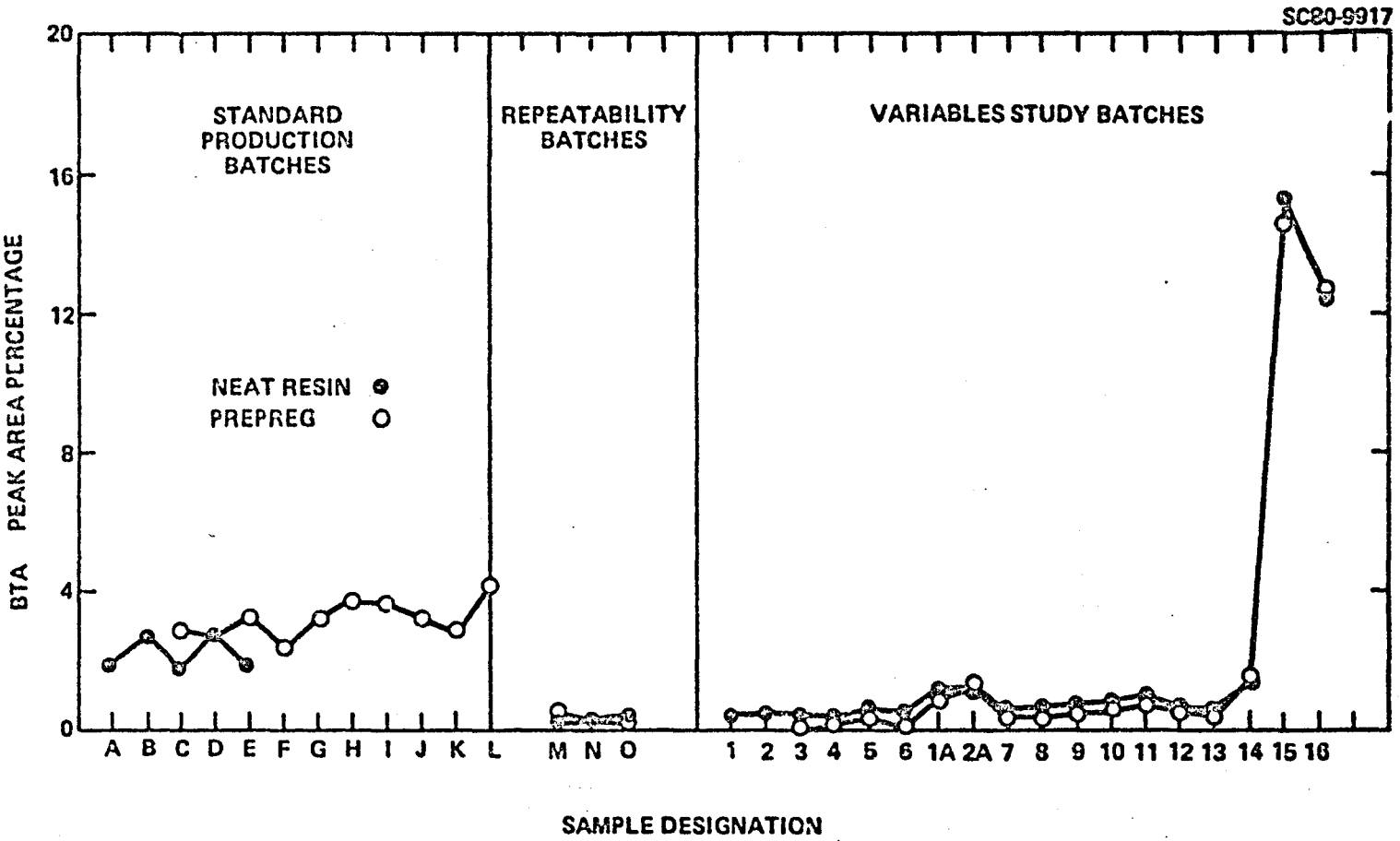


Figure 3. Liquid Chromatographic Analysis of BTDA Tetraacid in Hexcel LARC-160 Neat Resins and Prepregs.

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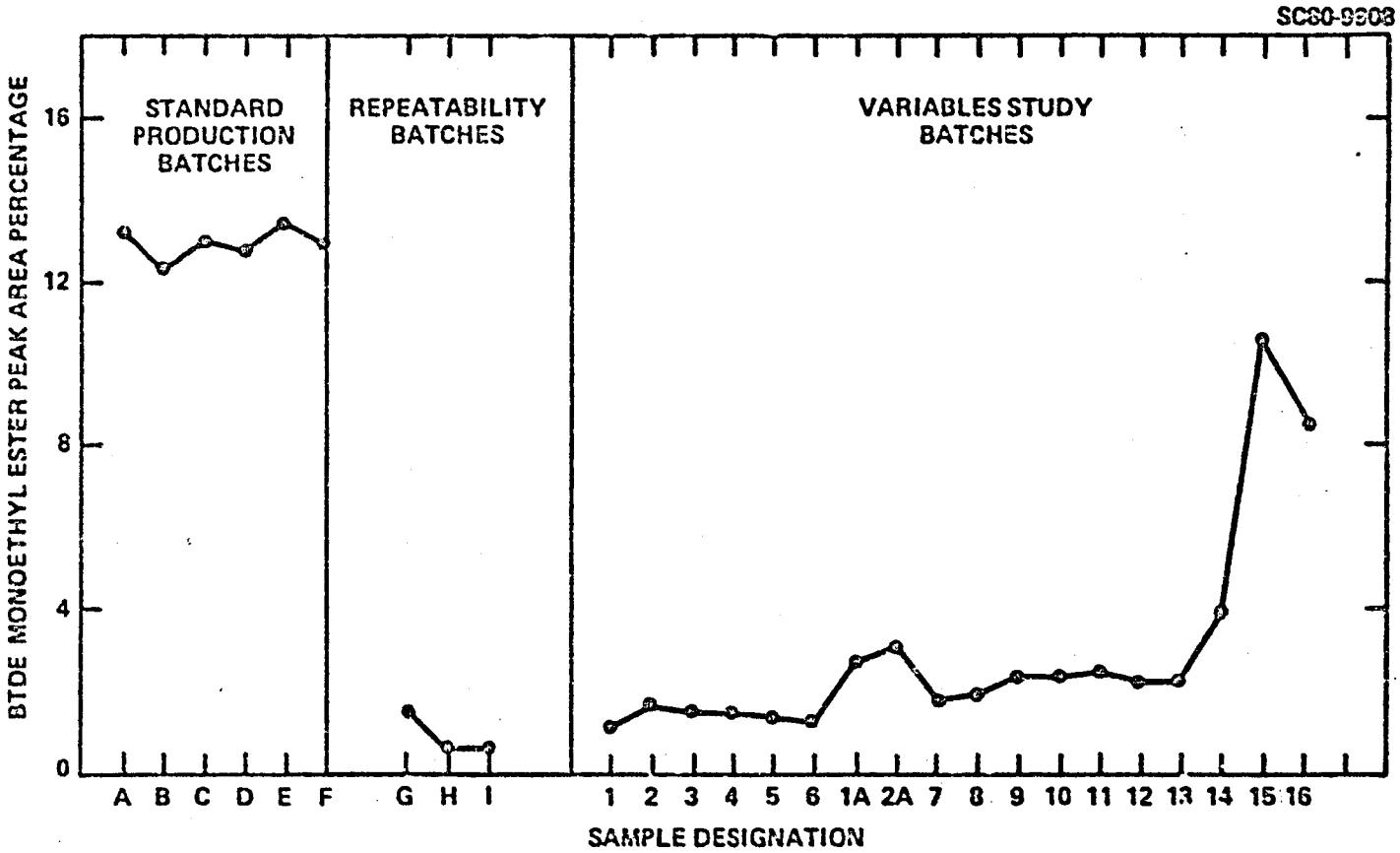
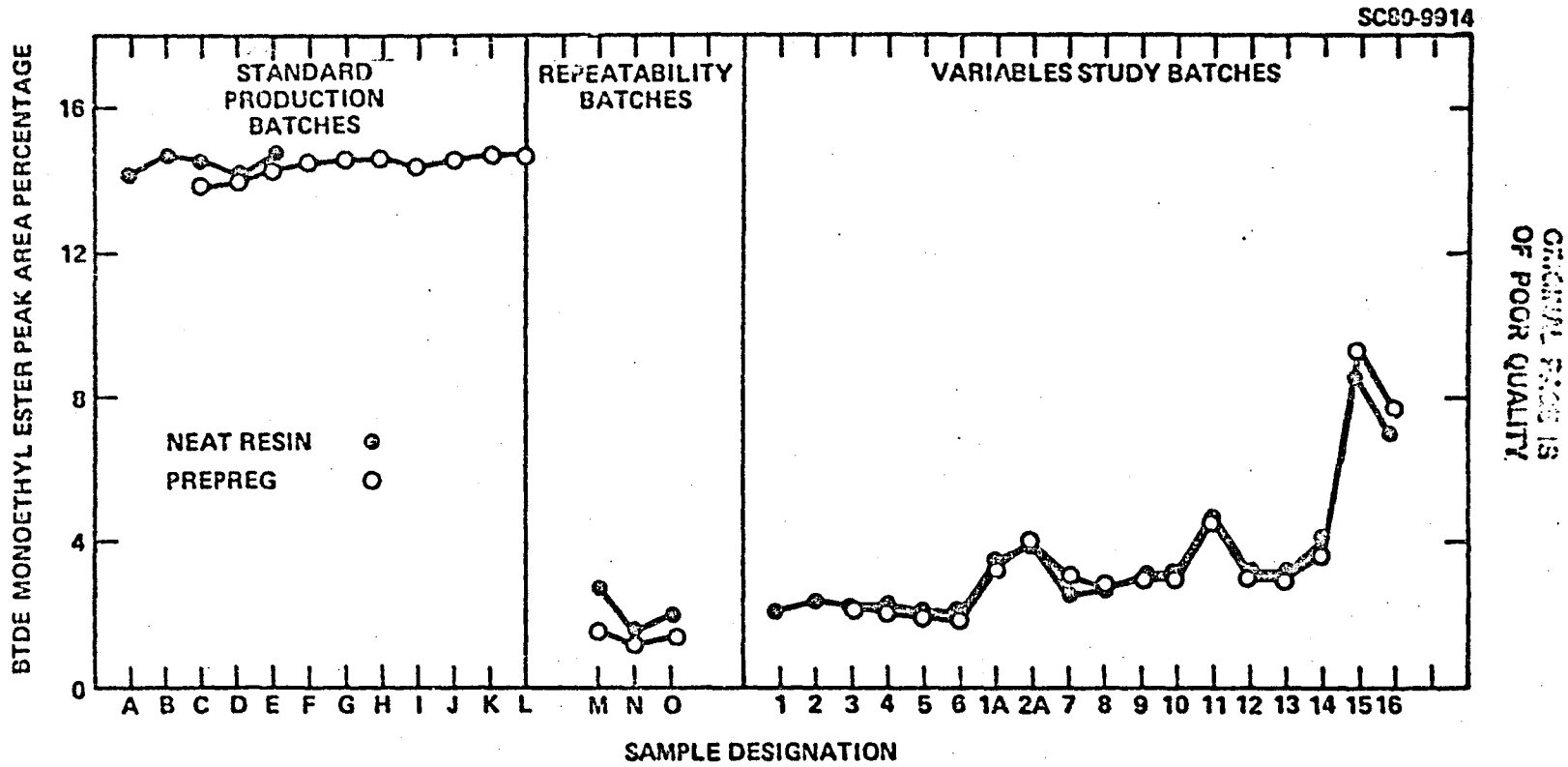


Figure 4. Liquid Chromatographic Analysis of BTDE Monoethyl Ester in Hexcel LARC-160 Intermediate Ester Mixtures.



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Figure 5. Liquid Chromatorgraphic Analysis of BTDE Monoethyl Ester in Hexcel LARC-160 Neat Resins and Prepregs.

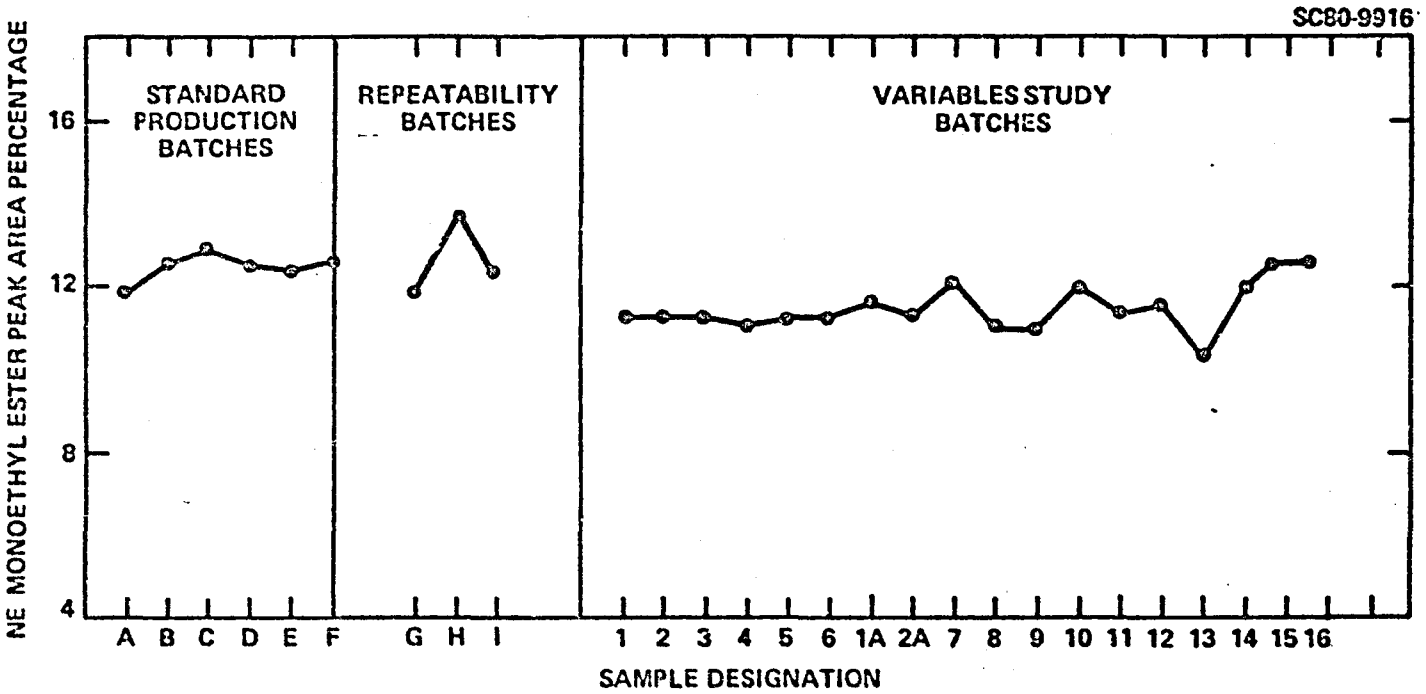


Figure 6. Liquid Chromatographic Analysis of NE Monoethyl Ester in Hexcel LARC-160 Intermediate Ester Mixtures.

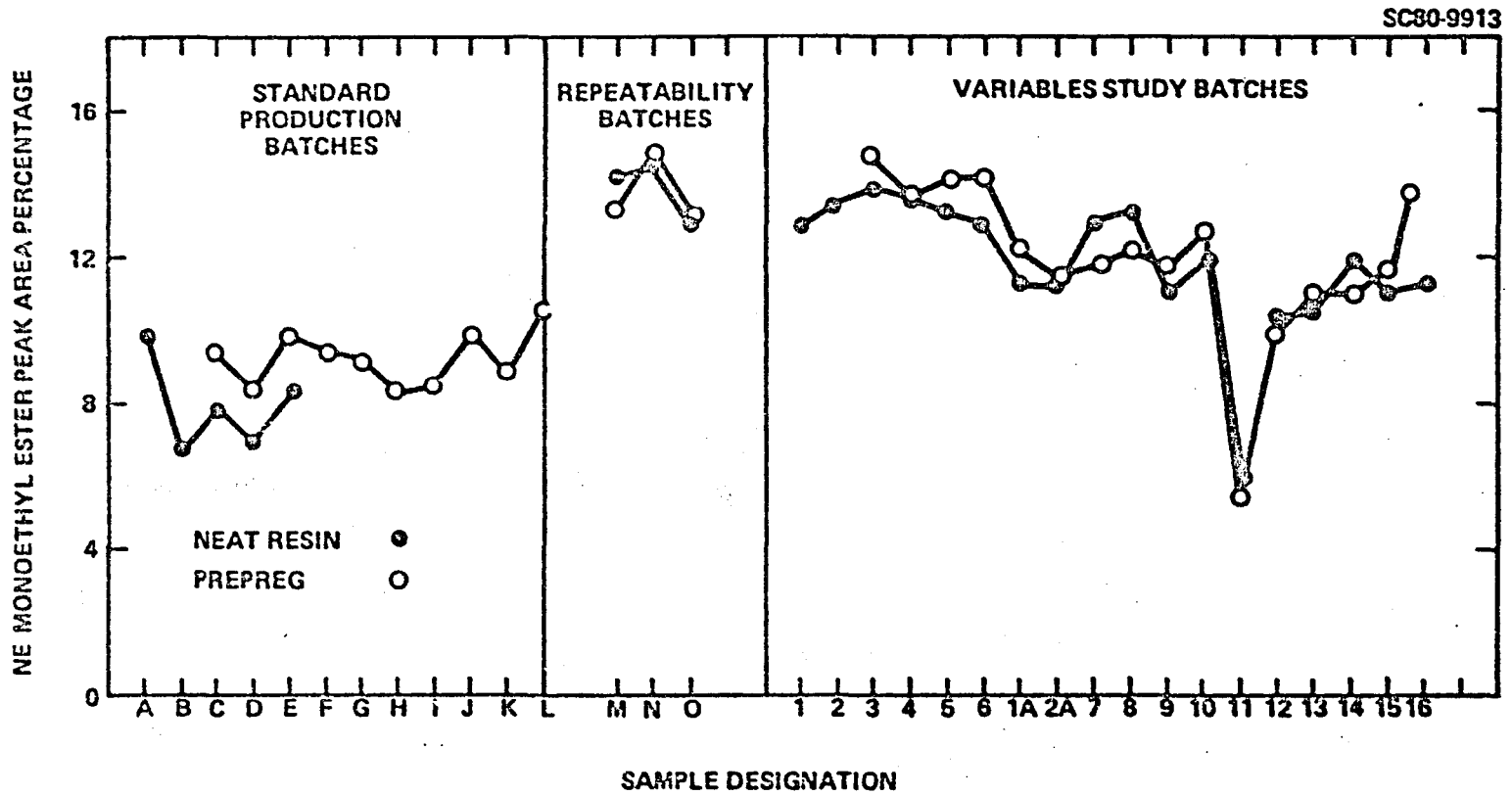


Figure 7. Liquid Chromatographic Analysis of NE Monoethyl Ester in Hexcel LARC-160 Neat Resins and Prepregs.

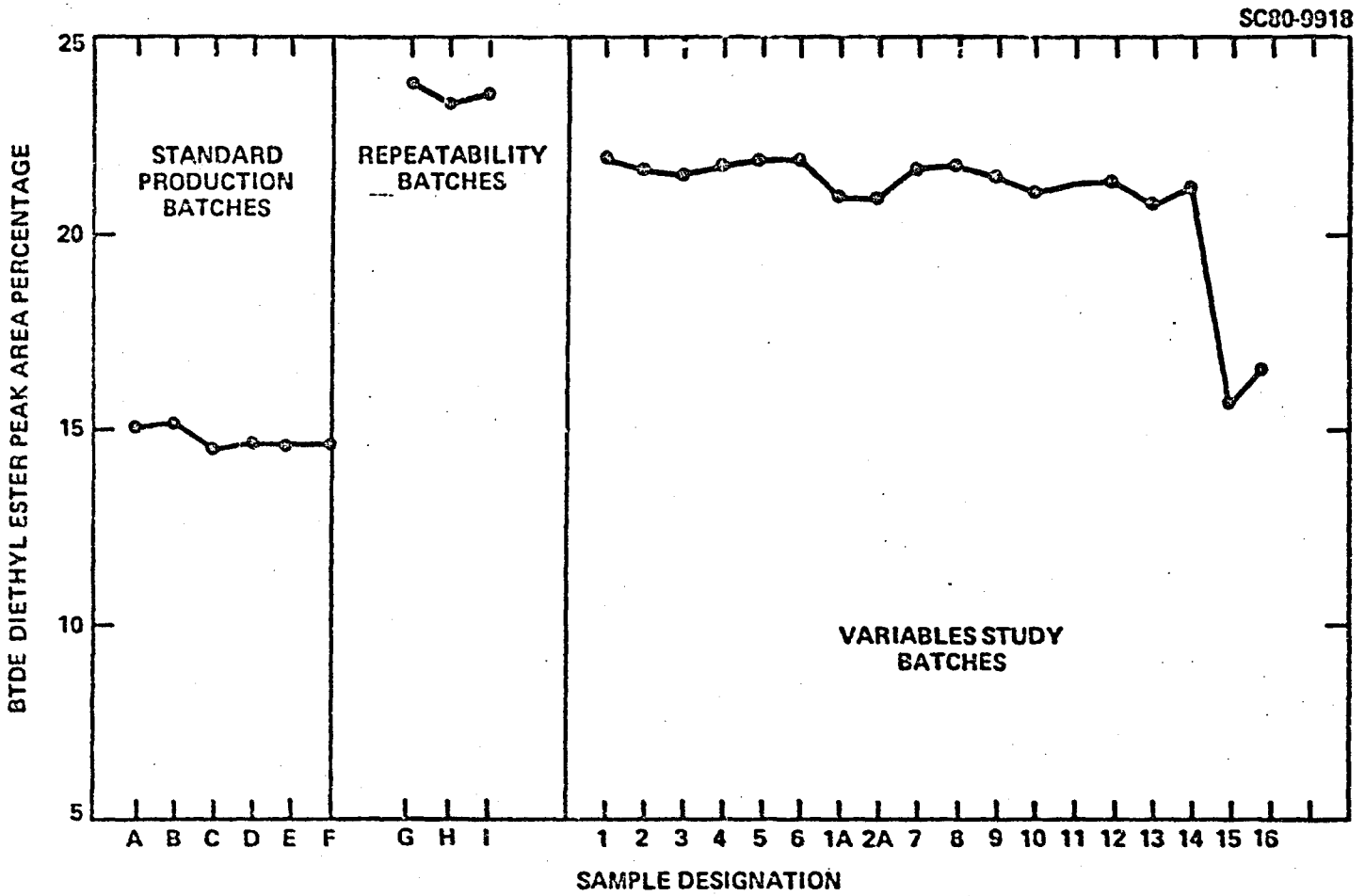


Figure 8. Liquid Chromatographic Analysis of BTDE Diethyl Ester in Hexcel LARC-160 Intermediate Ester Mixtures.

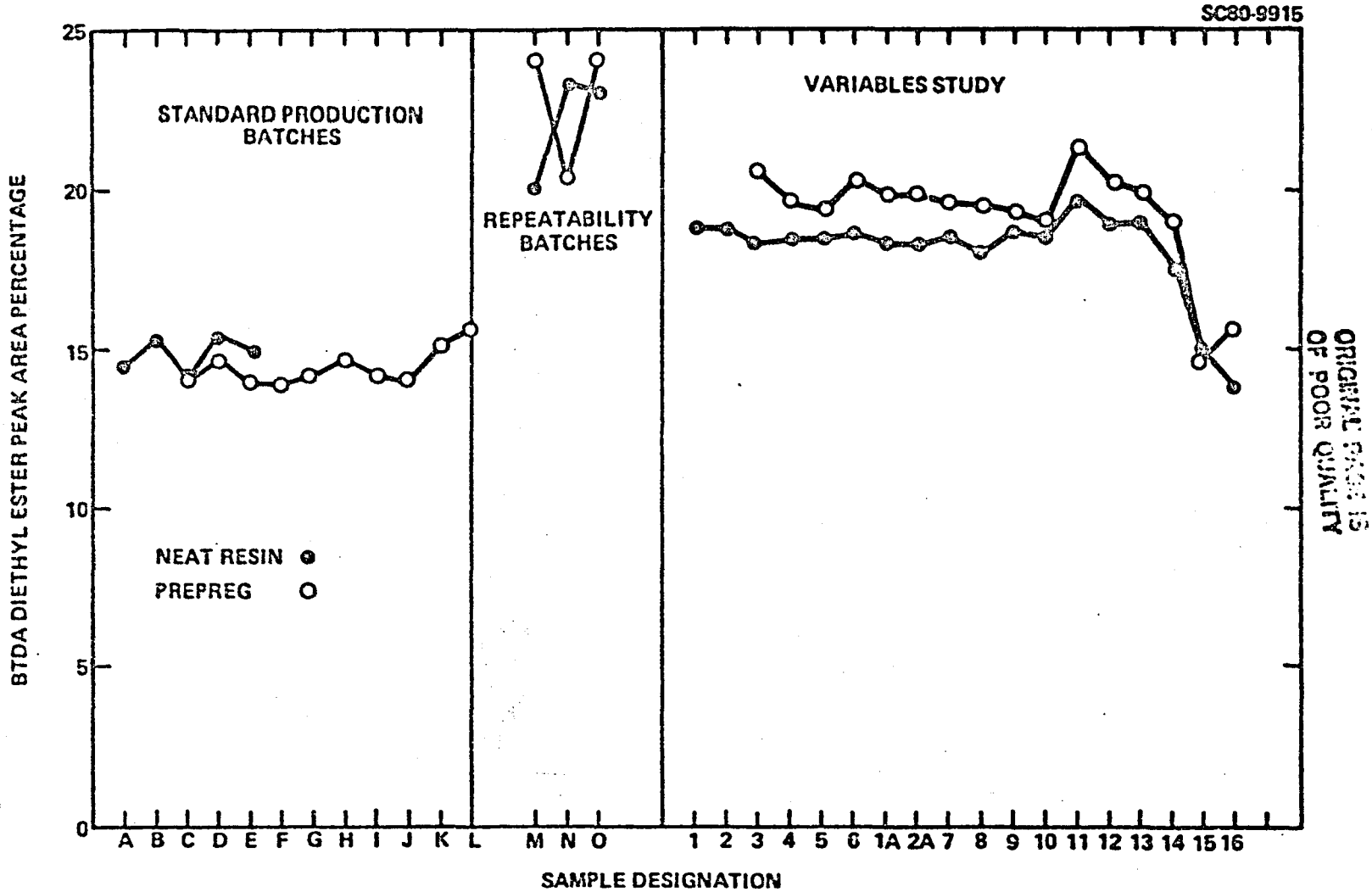


Figure 9. Liquid Chromatographic Analysis of BTDE Diethyl Ester in Hexcel LARC-160 Neat Resins and Prepregs.

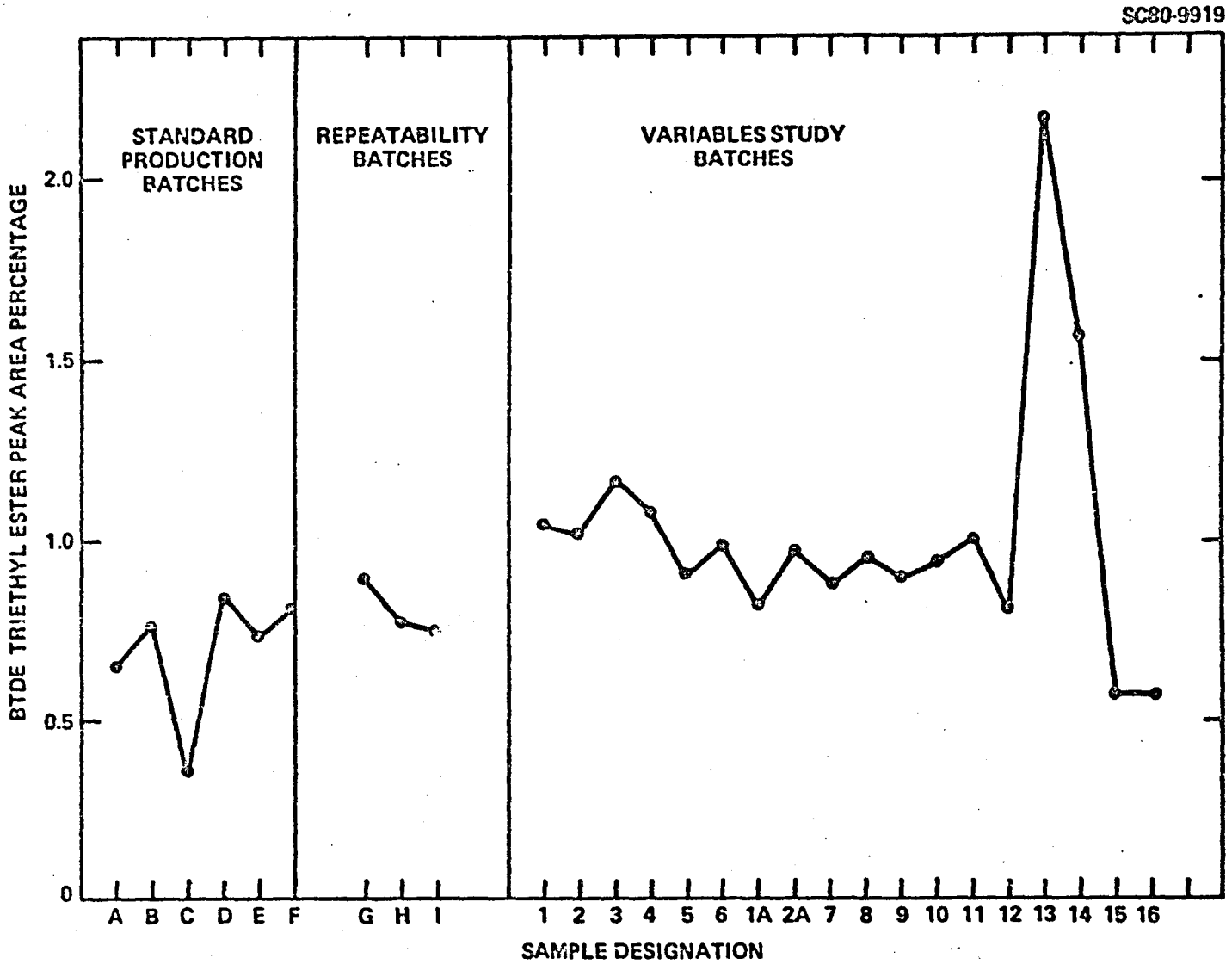


Figure 10. Liquid Chromatographic Analysis of BTDE Triethyl Ester in Hexcel LARC-160 Neat Resin and Prepregs.

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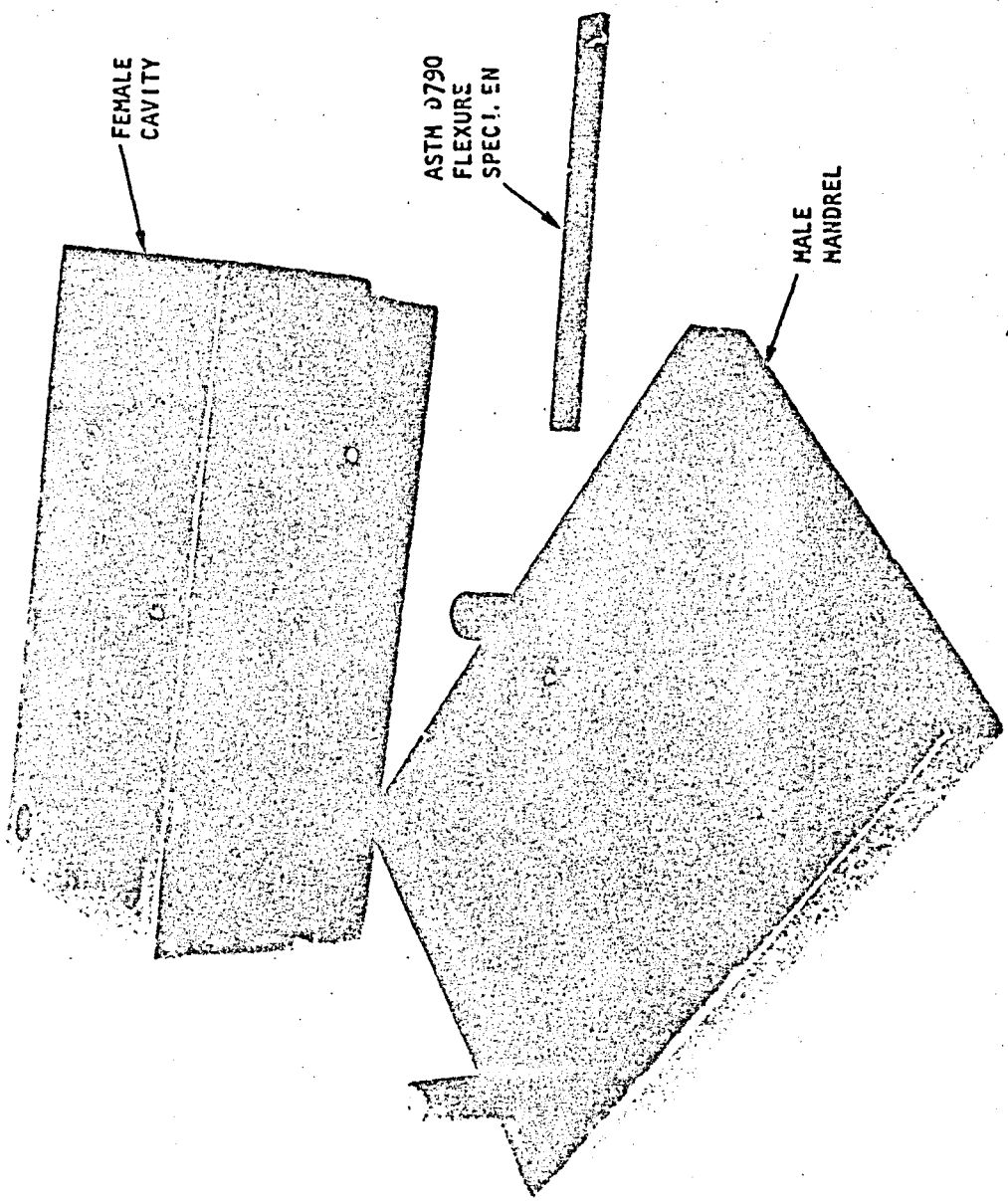
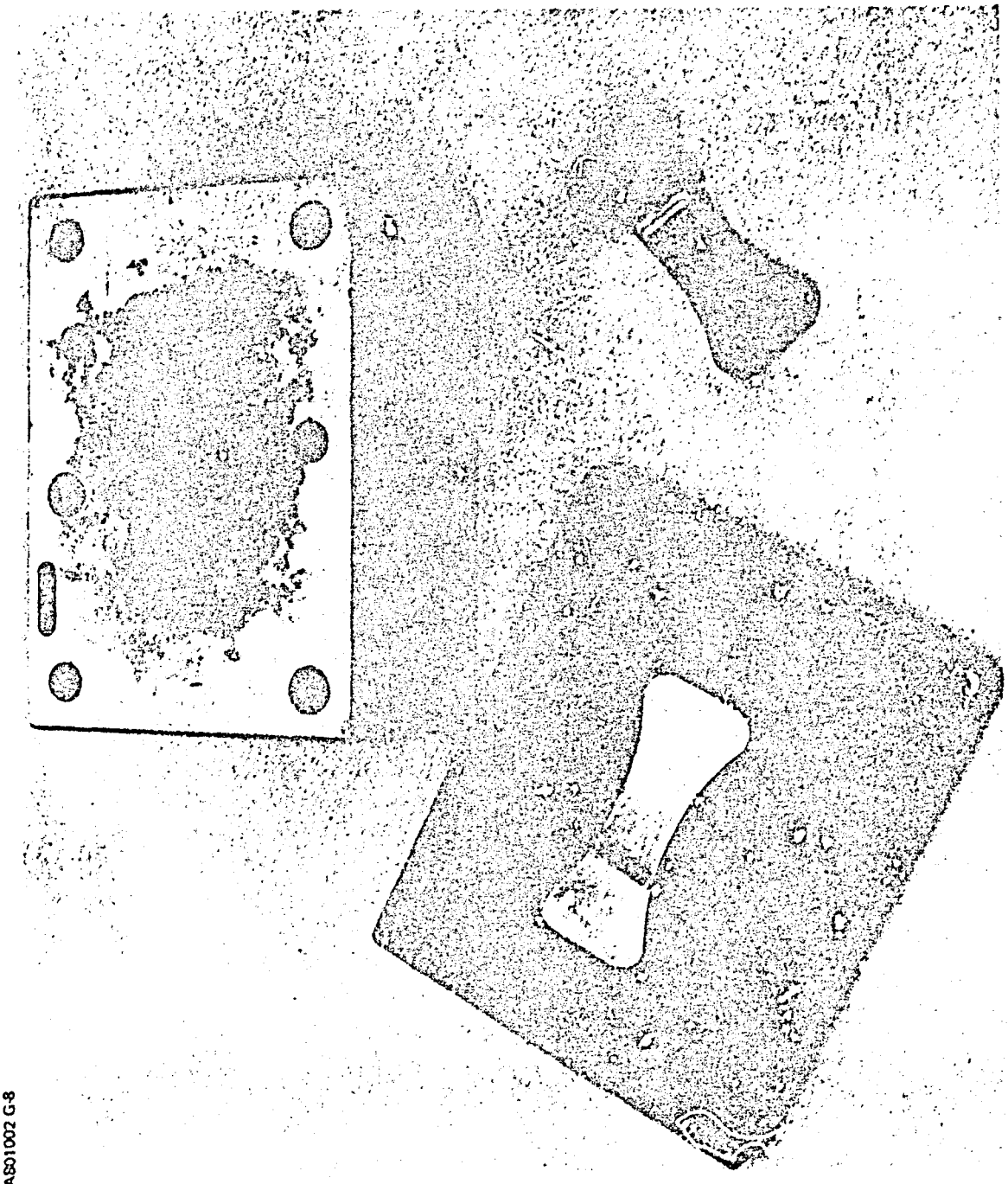


Figure 11. ASTM D 647 Compression Mold for Celion/LARC 160 Molding Compound Flexure Specimen per ASTM D 790

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Figure 12. ASTM D647 Tensile Mold and Molded ASTM D611 Tension Coupon

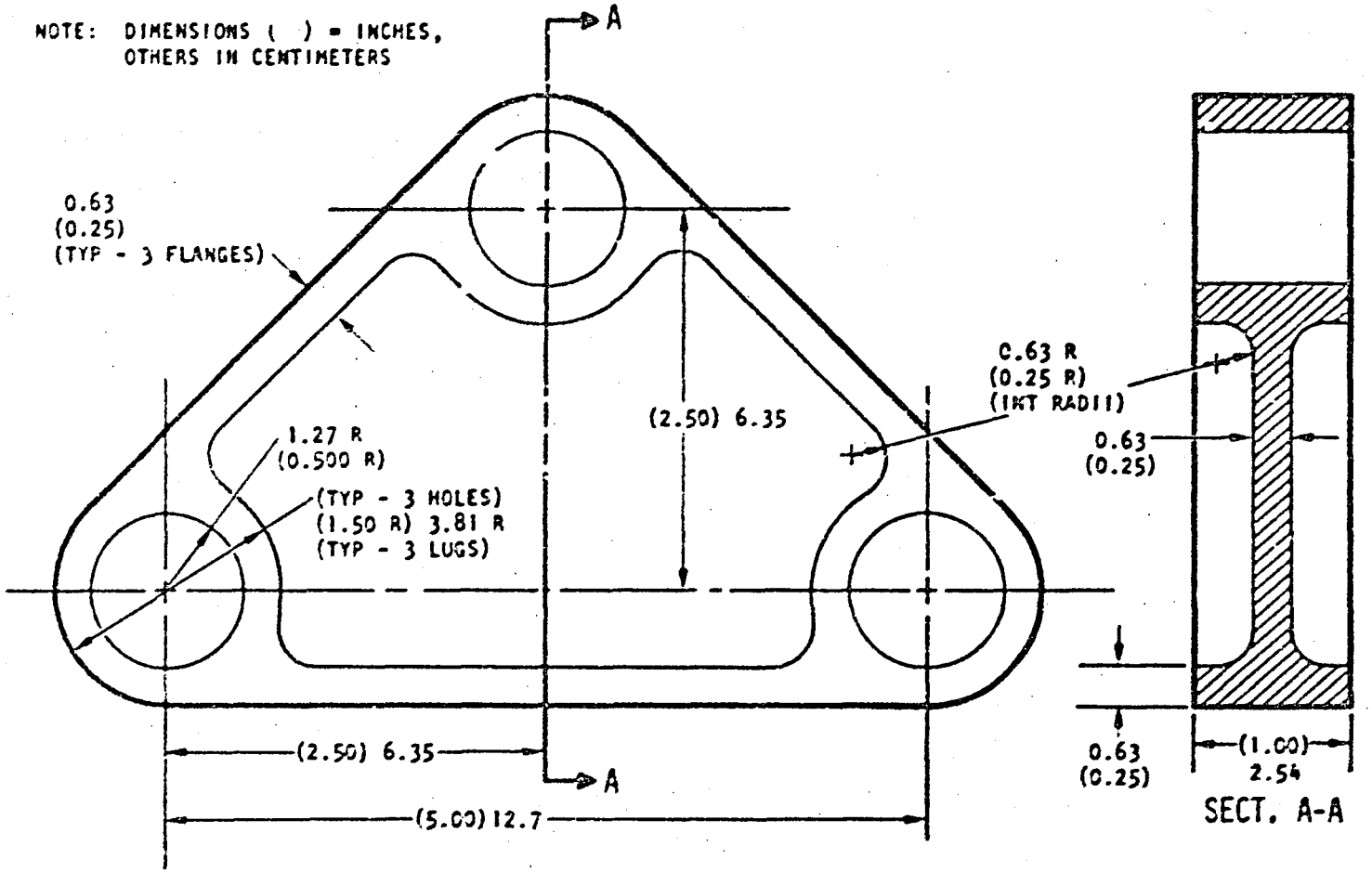


Figure 13. Molding Compound Process Demonstration Part Design

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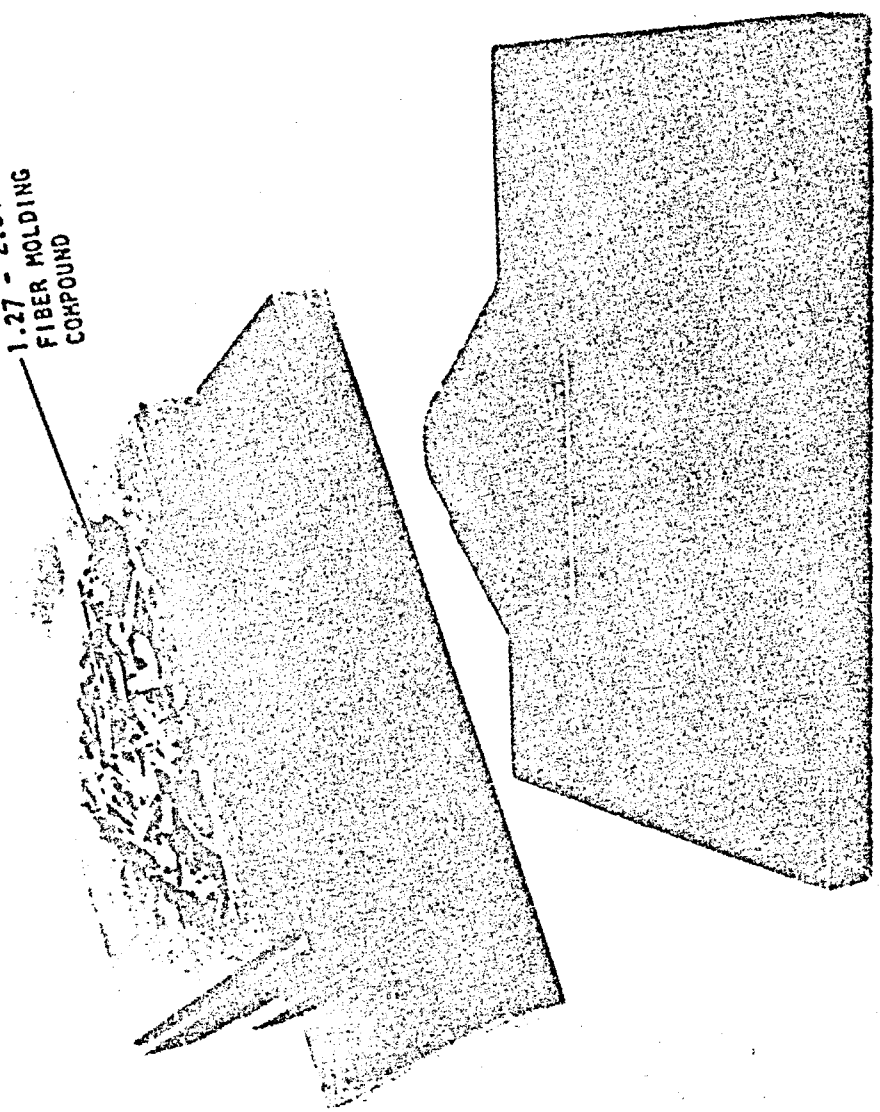


Figure 14. Celion/LARC 160 Molding Compound Complex Part Demonstration Mold

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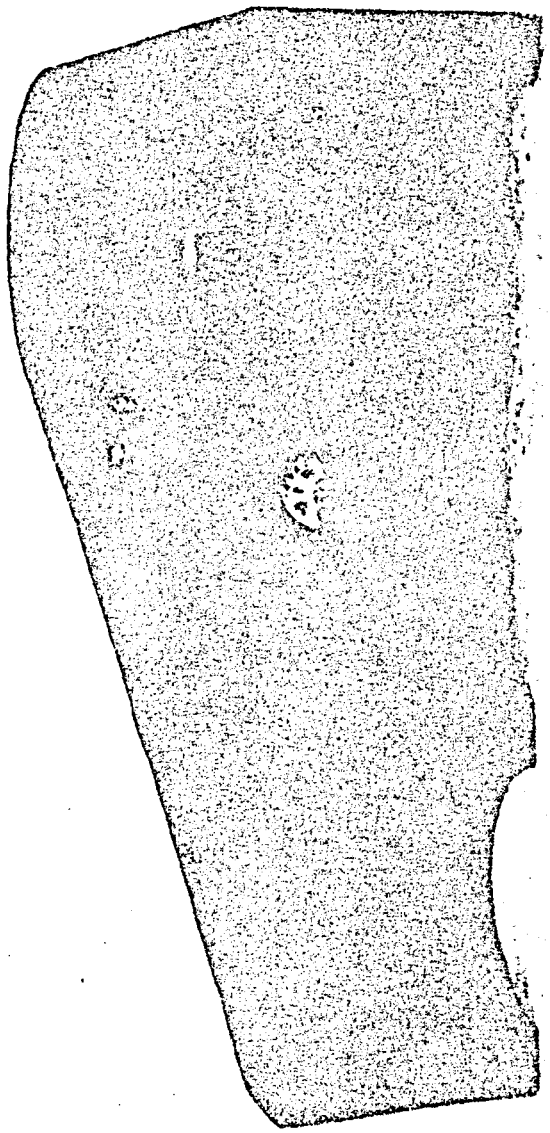


Figure 15. Complex Shaped Process Demonstration Part Showing Blistered Web Area—
Inidized at 191°C (375°F), Removed From Mold Hot

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Figure 16. Poor Flow and Mold Conformance of Molding Compound Inidized at 204°C (400°F)

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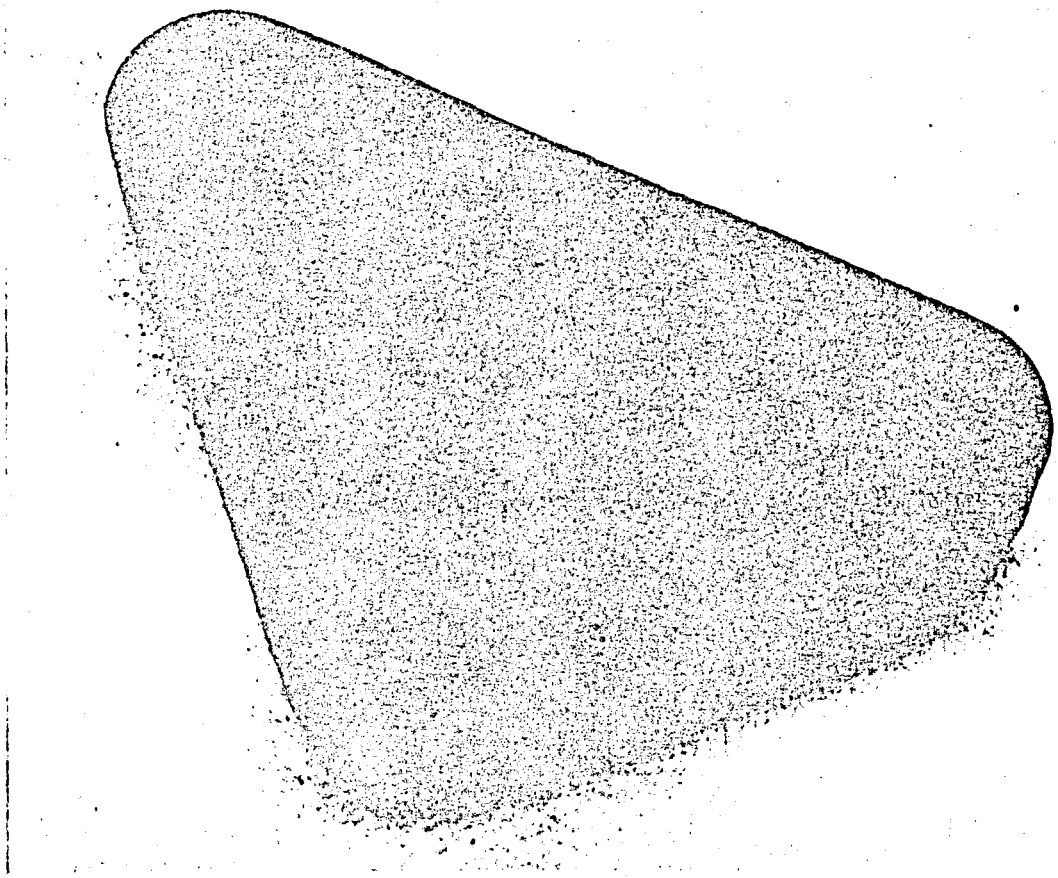


Figure 17. Complex Shaped Process Demonstration Part Showing Good Compound Flow and Mold Conformance—Imidized at 191°C (375°F), Removed From Mold Cold

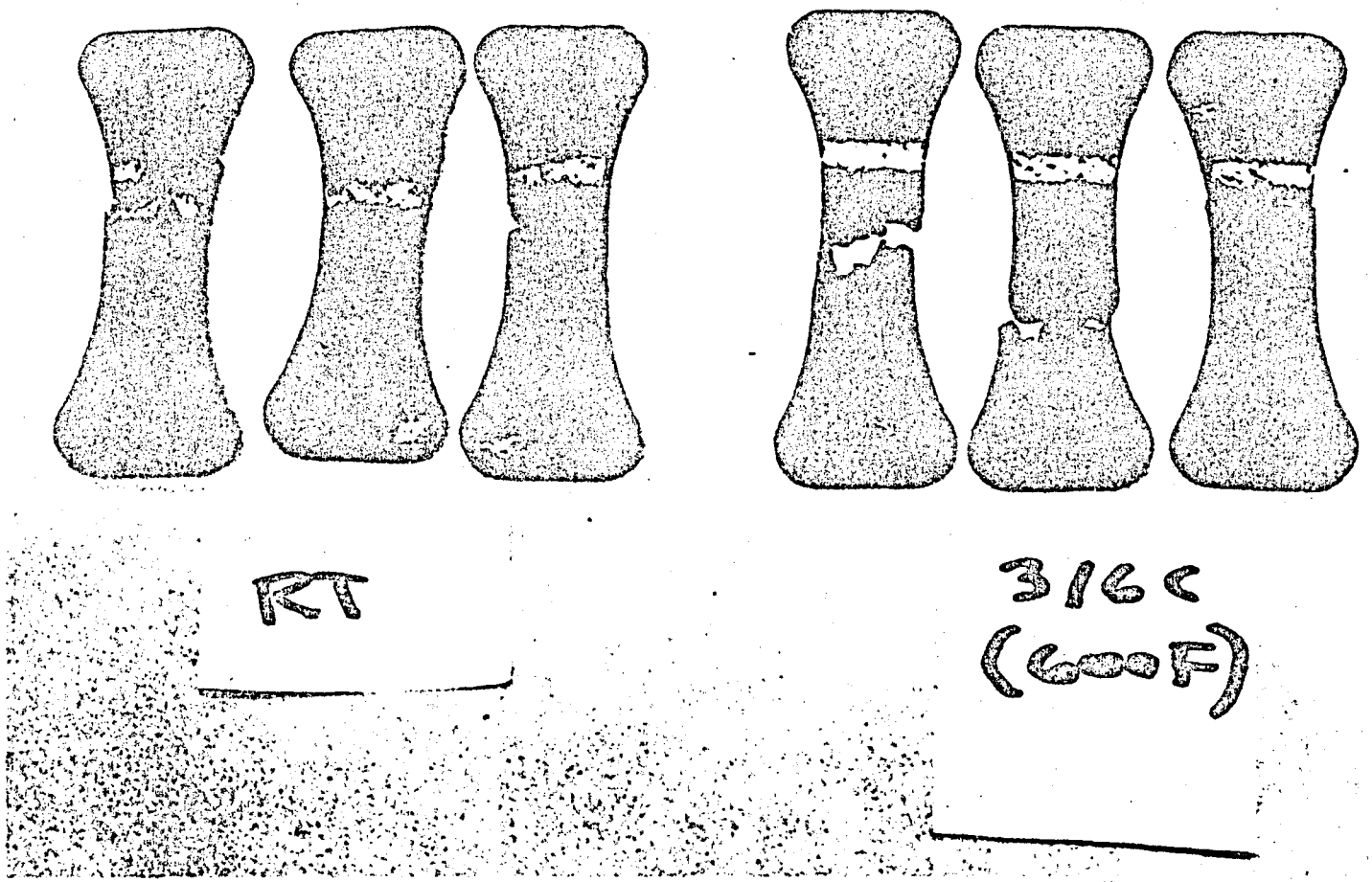


Figure 18. Tensile Specimen—Interlaminar Shear Failure Modes—Short Fiber Molding Compound

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TABLE I

HEXCEL LARC-160 INTERMEDIATE ESTER BATCHES

Standard Production Batches

A	22367 544 Run 2	Standard Composition & Processing
B	22361 544 Run 4	Standard Composition & Processing
C	22403 545 Run 1	Standard Composition & Processing
D	22746 545 Run 1	Standard Composition & Processing
E	22746 545 Run 2	Standard Composition & Processing
F	22746 545 Run 3	Standard Composition & Processing

Repeatability Batches

G	23724	Standard Composition & Processing
H	23726	Standard Composition & Processing
I	23728	Standard Composition & Processing

Variables Study Batches

1	22943	Standard Composition & Processing
2	22944	Standard Composition & Processing
3	22945	Standard Composition & Processing
4	22946	Standard Composition & Processing
5	22947	Standard Composition & Processing
6	22948	Standard Composition & Processing
1A	22990	Standard Composition & Processing
2A	22991	Standard Composition & Processing
7	22949	+5% NA, Standard Processing
8	22950	+5% BTDA, Standard Processing
9	22951	-5% NA, Standard Processing
10	22952	-5% BTDA, Standard Processing
11	22953	Standard Composition & Processing
12	22954	Standard Composition & Processing
13	22955	Standard Composition, 6 hr Reflux
14	23107	Standard Composition & Processing
15	23236	Standard Composition & Processing
15A	To Be Prepared	Standard Composition & Processing
16	23357	Standard Composition & Processing
16A	To Be Prepared	Standard Composition & Processing

TABLE 2

HEXCEL LARC-160 NEAT RESIN AND PREPREG BATCHES

	Neat Resin	Prepreg
A	544 22408	Not Available
B	544 22513	Not Available
C	544 22368 Cut 3	22368 Roll 1
D	544 22361 Cut 4	22361 Roll 1
E	544 22367 Cut 2	22367 Roll 1
F	Not Available	22322 Roll 1
G	544 22332 Cut 1	22332 Cut 1
H	Not Available	22999-2
I	Not Available	22999-3
J	Not Available	22999-4
K	Not Available	22999-II
L	Not Available	23091 Roll 4

Repeatability Batches

M	23724	23723
N	23726	23725
O	23728	23727

Variable Study Batches

	Neat Resin	Prepreg	
1	22943	22943	+2% AP-22, Standard Processing
2	22944	22944	-2% AP-22, Standard Processing
3	22945	22945	+5% AP-22, Standard Processing
4	22946	22946	-5% AP-22, Standard Processing
5	22947	22947	+10% AP-22, Standard Processing
6	22948	22948	-10% AP-22, Standard Processing
1A	22990	22990	+2% AP-22, Standard Processing
2A	22991	22991	-2% AP-22, Standard Processing
7	22949	22949	+5% NA Standard Processing
8	22950	22950	+5% BTDA Standard Processing
9	22951	22951	-5% NA Standard Processing
10	22952	22952	-5% BTDA Standard Processing
11	22953	22953	Standard Composition, Extended Resin Cook
12	22954	22954	Standard Comp., Intermediate Resin Cook
13	22955	22955	Standard Composition, 6 hr Ester Reflux
14	22956	23107	Anchamine DL, Std. Comp. & Proc.
15	23236	23236	Tonox-22, Standard Composition & Proc.
15A	To Be Prepared		Tonox-22, Standard Composition & Proc.
16	23357	23427	Standard Composition & Processing
16A	To Be Prepared		Standard Composition & Processing

Table 3. Flexural Properties of Celion/LARC 160 Chopped Unidirectional Tape Molding Compounds

Processing Variable		Imidized Prepreg Variables			Specimen Number(2)	Composite Physical Properties				F_{fu} (3)		E_f (3)	
										22 C (75 F)			
Imidizing Temperature C (F)	Imidizing Time (mins)	Resin Solids (%)	Volatile Content (%)	Fiber(1) Length Cm (inch)		Density (gram/cc)	Resin Content (%)	Fiber Volume (%)	Void Volume (%)	Mn/m^2 (avg)	(Ksi)	Gn/m^2 (avg)	(Msi)
191 (375)	60	40.8	1.5-2.75	1.27 - 2.54 (0.5 - 1.0)	CF1-1*	1.565	34.1	58.9	0.01		81.9		11.4
					CF1-2	1.540	39.8	53.0	-0.13		75.9		9.9
					CF1-3	1.550	38.8	54.2	-0.46		97.4		11.2
										586 avg	85.1	74.4 avg	10.8
										316 C (600 F)			
					CF1-4					497	72.2	72.3	10.5
										22 C (75 F)			
191 (375)	60	36.8	1.4-2.3	1.27 (0.50)	GE1	1.55	37.8	55.1	-0.16		46.9		5.4
					GE2	—	—	—	—		33.6		5.6
					GE3	—	—	—	—		27.3		5.4
										245	35.6	37.9 avg	5.5
										316 C (600 F)			
					GE4	1.54	38.8	53.9	0.17		22.4		4.2
					GE5	—	—	—	—		21.7		4.7
					GE6	—	—	—	—		41.3		6.5
										196 avg	28.5	35.1	5.1

(1) Molding compound with fiber length 1.27 to 2.54 cm (0.5 to 1.0 inch) was made in the laboratory by a random chopping procedure using a paper cutter; 66.8 gram/m^2 areal fiber weight prepreg tape, NR 150B2 sizing, U.S.P. batch 2W4379. Molding compound with fiber length, 1.27 cm (0.5 inch) was accurately cut by U.S.P. from tape batch 2W4457, R1; 153.7 gram/m^2 areal fiber weight prepreg tape.

(2) Individual flexure coupons per ASTM D 790 were net molded at 13.78 Mn/m^2 (2000 psi) 316 ± 5.5 C (600 ± 10 F). Pressure was applied when part reached 204 C (400 F). Parts were force cooled under pressure to < 66°C (< 150 F)

(3) Load was applied at 0.127 cm (0.05 inch)/minute after stabilizing at 316 C (600 F) for 10 ± 5 minutes.

*CF1 insitu imidize process

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Table 4. Tensile Properties of Celion/LARC 160 Chopped Unidirectional Tape Molding Compounds

Processing Variables		Imidized Prepreg Variables			Specimen Number(2)	Composite Physical Properties								F_{tu}(3)	
						Density (gran/cc)		Resin Content (%)		Fiber Volume (%)		Void Volume (%)		22 C (75 F)	
Imidizing Temperature C (F)	Imidizing Time (mins)	Resin Solids (%)	Volatile Content (%)	Fiber(1) Length Cm (inch)		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	MN/m^2 (avg)	Ksi
191 (375)	60	40.8	1.5-2.75	1.27-2.54 (0.5-1.0)	CT1-1	—	—	—	—	—	—	—	—		28.1
					CT1-2	—	—	—	—	—	—	—	—		27.9
					CT1-3	—	—	—	—	—	—	—	—		28.3
														194 avg	28.1
														316 C (600 F)	
					CT1-4	—	—	—	—	—	—	—	—		26.2
					CT1-5	—	—	—	—	—	—	—	—		27.1
														184 avg	26.7
														22 C (75 F)	
191 (375)	60	36.8	1.4-2.3	1.27 (050)	GE13	1.533	1.524	41.4	41.8	51.3	50.7	-0.16	0.30		12.8
					GE14	1.530	1.526	41.1	41.3	51.5	51.2	0.13	0.33		20.5
					GE15	-	-	-	-	-	-	-	-		13.4
					GE19	-	-	-	-	-	-	-	-		21.0
														116 avg	16.9
														316 C (600 F)	
					GE16	1.5333	1.527	40.9	40.5	51.8	51.9	0.00	0.52		11.3
					GE17	1.538	1.526	40.4	41.4	52.4	51.4	0.10	0.29		16.4
					GE18	1.536	1.528	39.9	41.4	52.7	51.2	0.11	0.17		11.4
														89.6 avg	13.0

(1) Molding compound with fiber length 1.27 to 2.54 CM (0.5 to 1.0 inch) was made in the laboratory by a random chopping procedure using a paper cutter; 66.8 gram/m^2 areal fiber weight prepreg tape, NR 150B2 sizing, U.S.P. batch 2W4379. Molding compound with fiber length, 1.27 CM (0.5 inch) was accurately cut by U.S.P. from tape batch 2W4457, R1; 153.7 gram/m^2 areal fiber weight prepreg tape.

(2) Individual tensile coupons per ASTM D 651 were net molded at 13.78 MN/m^2 (2000 psi) 316 ±5 C (600 ±10 F) for 1 hour. Pressure was applied when part reached 204 C (400 F). Parts were force cooled under pressure to ≤ 66 C (< 150 F).

(3) Tensile force was applied at 0.127 CM (0.05 inch)/minute after stabilizing at 316 C (600 F) for 10 ±5 minutes.

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